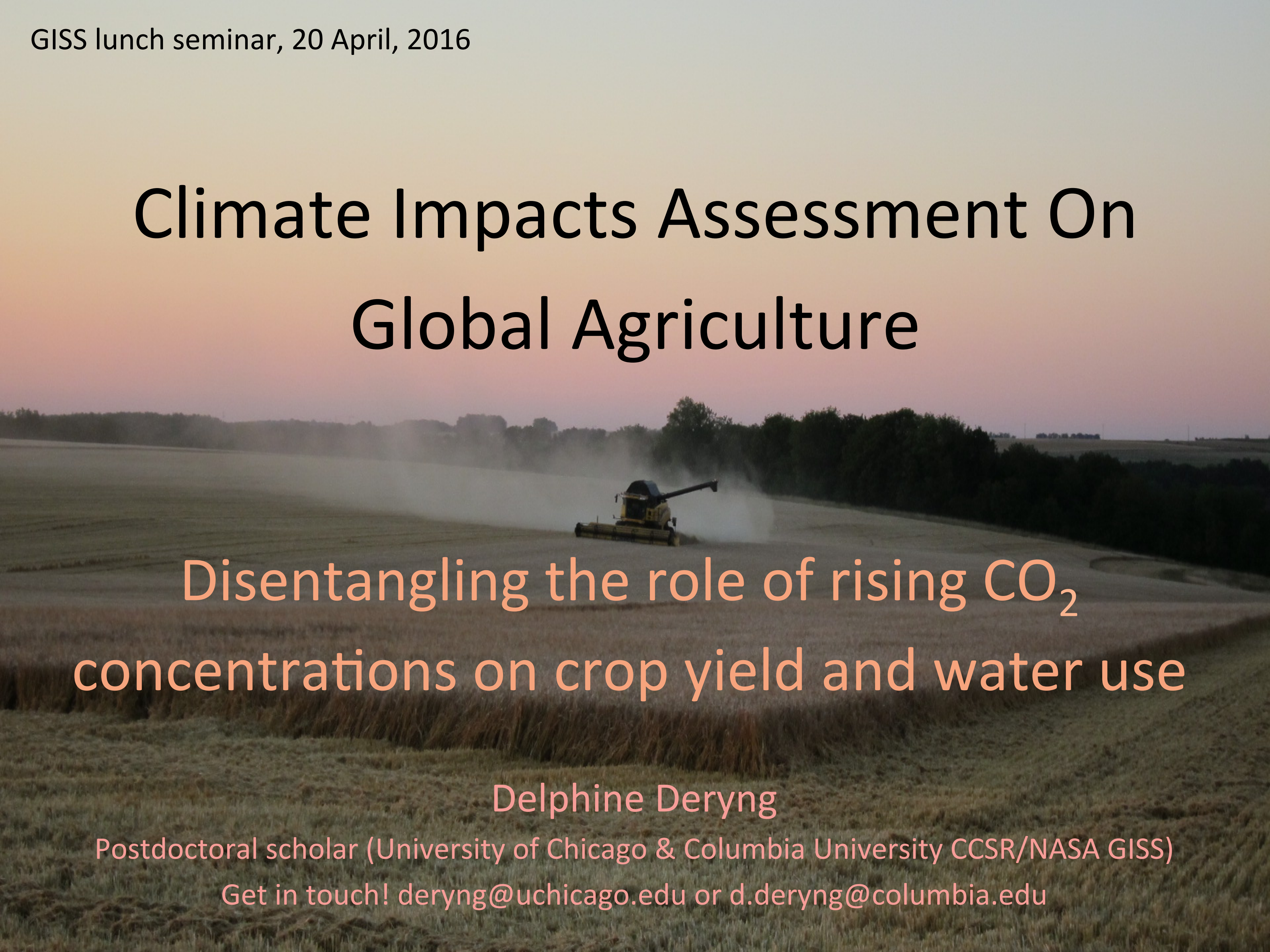

GISS lunch seminar, 20 April, 2016

Climate Impacts Assessment On Global Agriculture

Disentangling the role of rising CO_2 concentrations on crop yield and water use

Delphine Deryng

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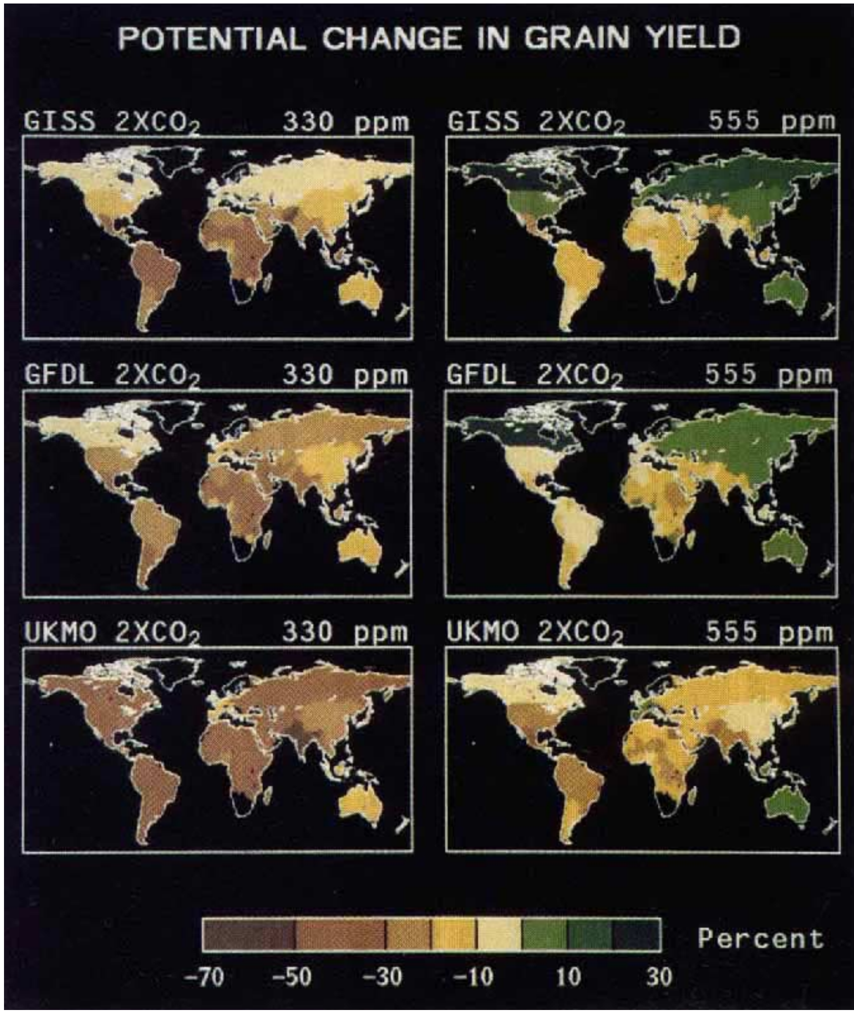
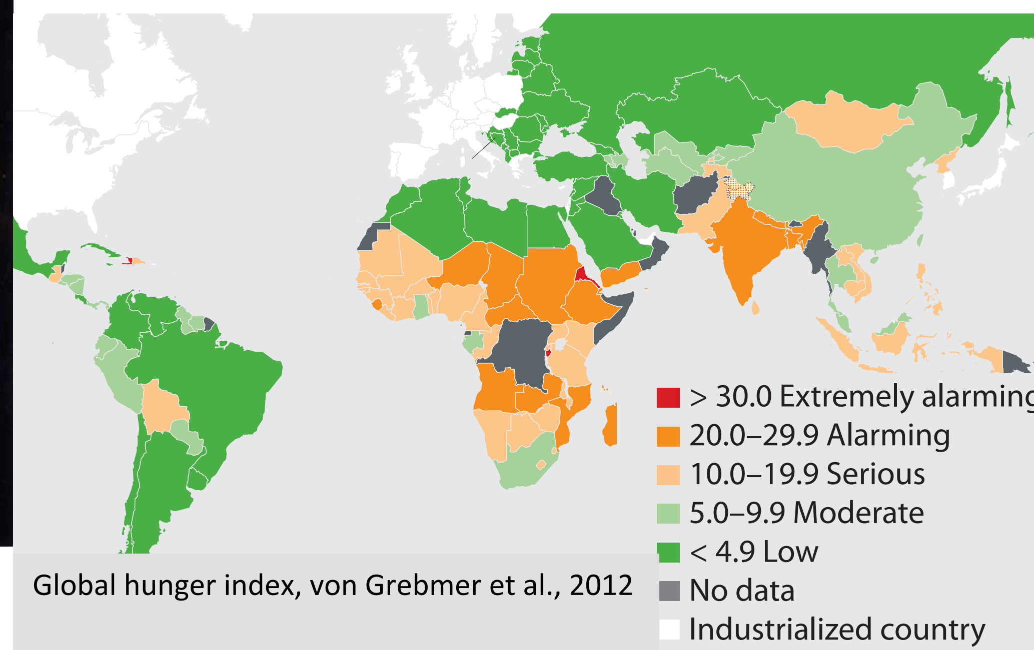
Potential Impacts of Climate Change on Crops



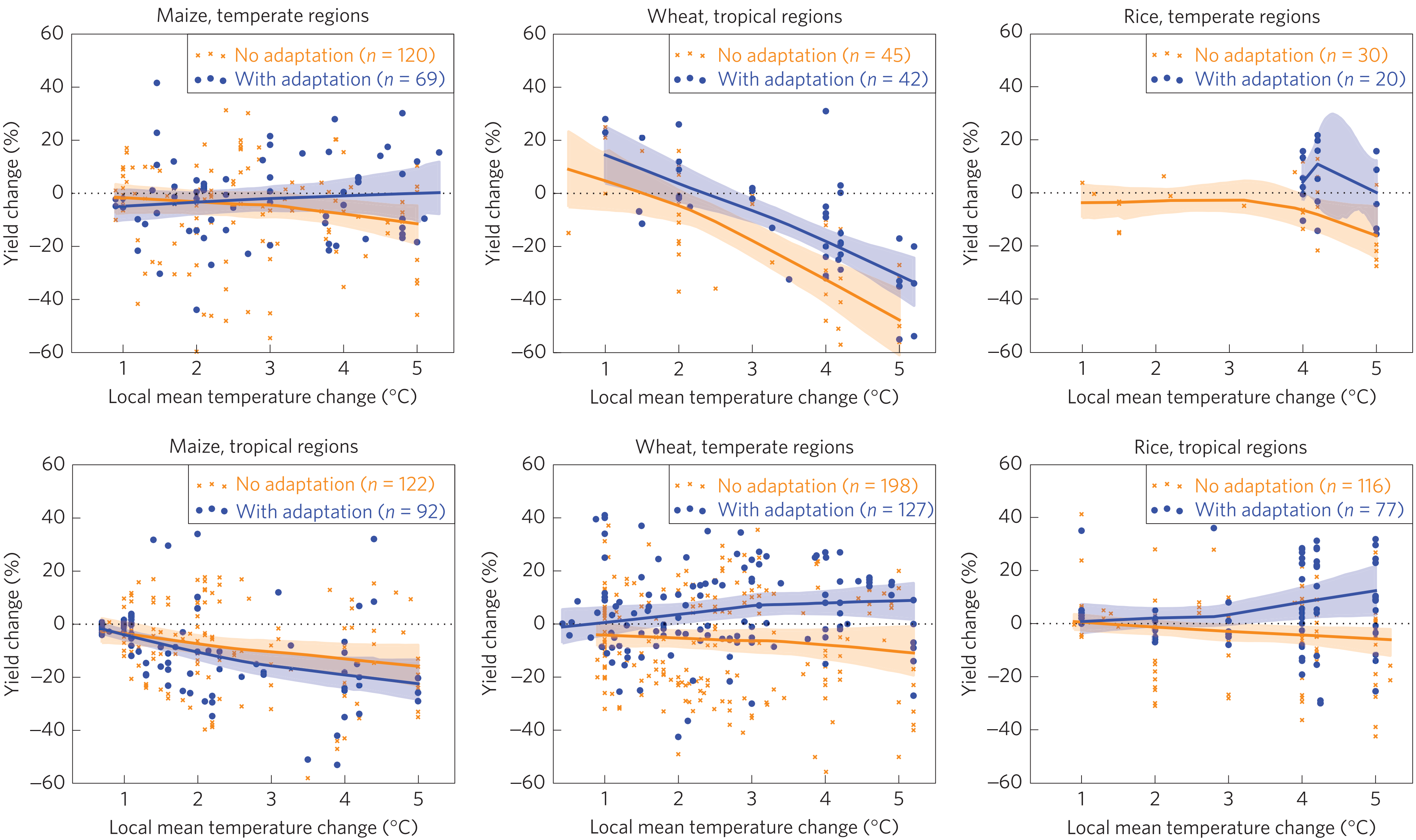
Rosenzweig & Parry, 1994

"…doubling of the atmospheric carbon dioxide concentrations of crops will lead to only a small decrease in global crop productions. But developing countries are likely to bear the brunt of the problem…"



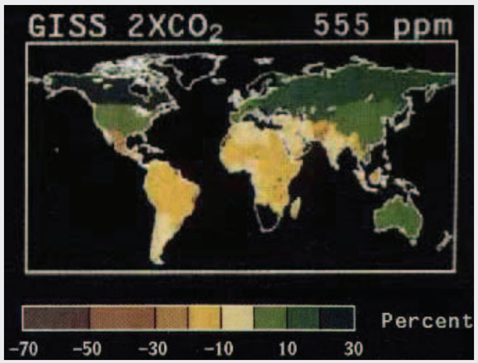
Global hunger index, von Grebmer et al., 2012

Synthesis for the last IPCC report

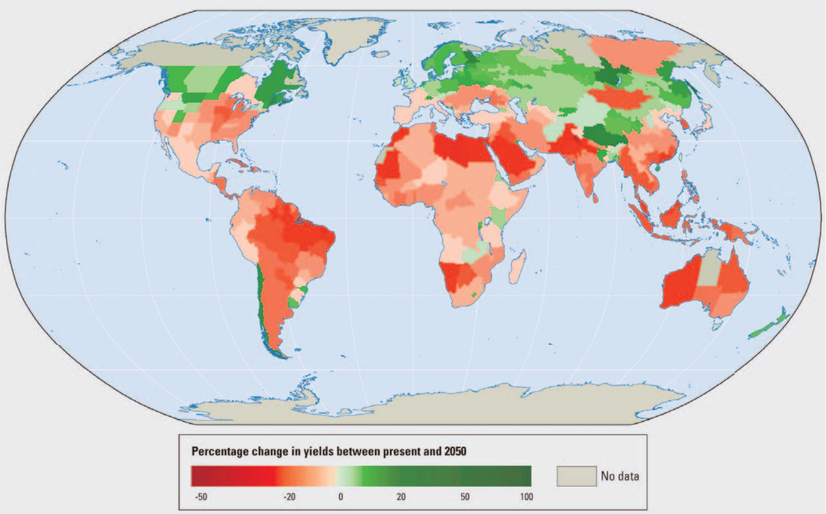


IPCC AR5 WG2, Chap7 (2014) & Challinor et al., 2014

Review: climate change and food security



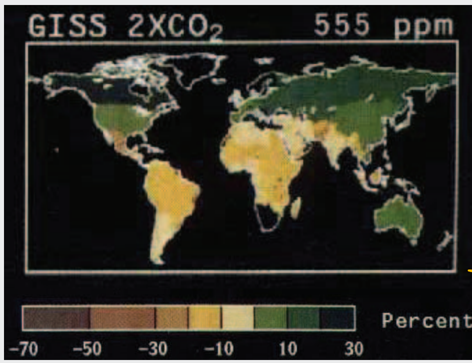
Rosenzweig & Parry, 1994



World Development report, World Bank 2010

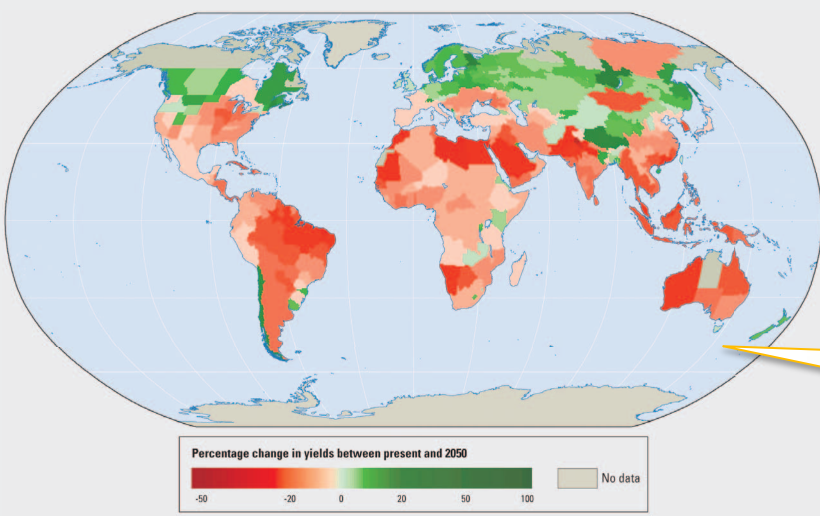
Wheeler, 2013

With and without CO_2?



Rosenzweig & Parry, 1994

Climate Change with CO_2 effects

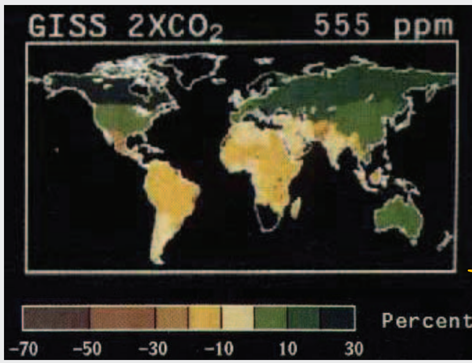


World Development Report, World Bank 2010

Climate Change without CO_2 effects

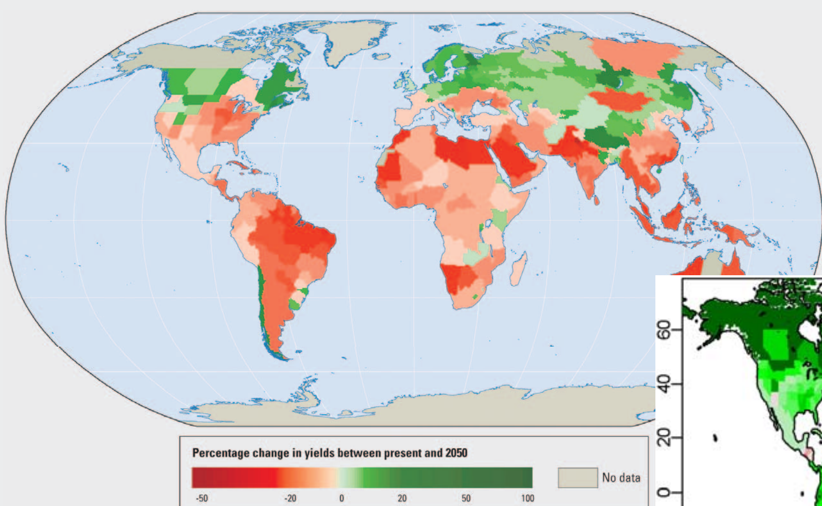
Wheeler, 2013

With or without CO_2?



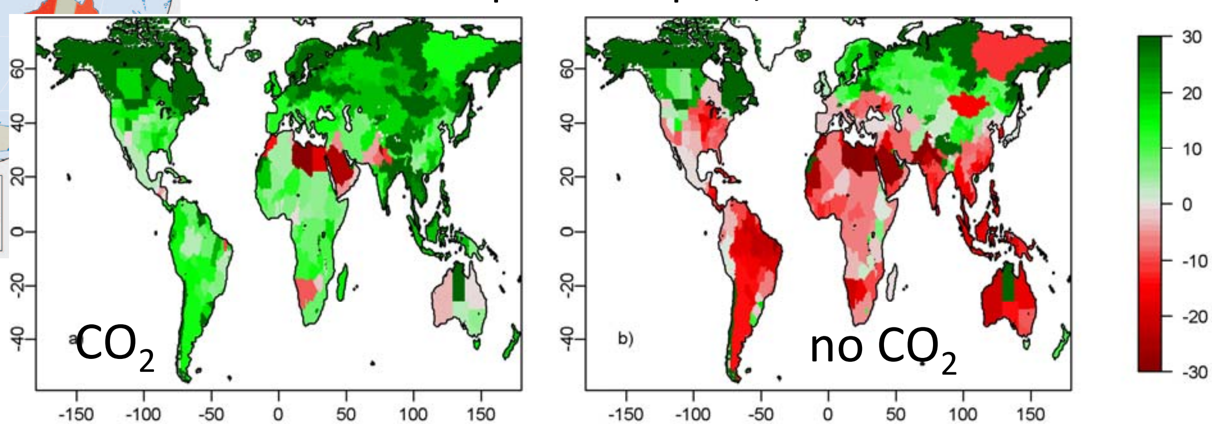
Rosenzweig & Parry, 1994

Climate Change with CO_2 effects



Wheeler, 2013

World Development report,2010



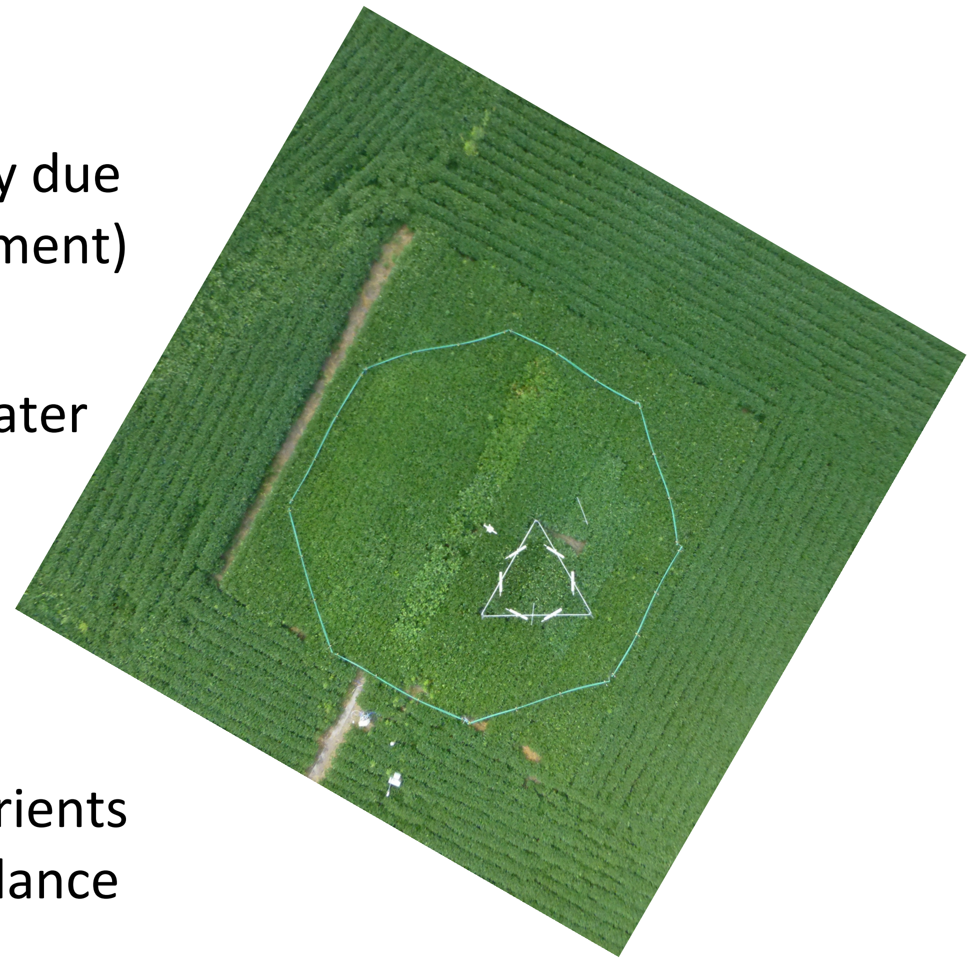
What do we know about these CO_2 effects on crops?

A doubling of atm. CO_2 concentrations:

- Increases yield of:

C_3 crops by ~10-45% (mainly due to photosynthesis enhancement)

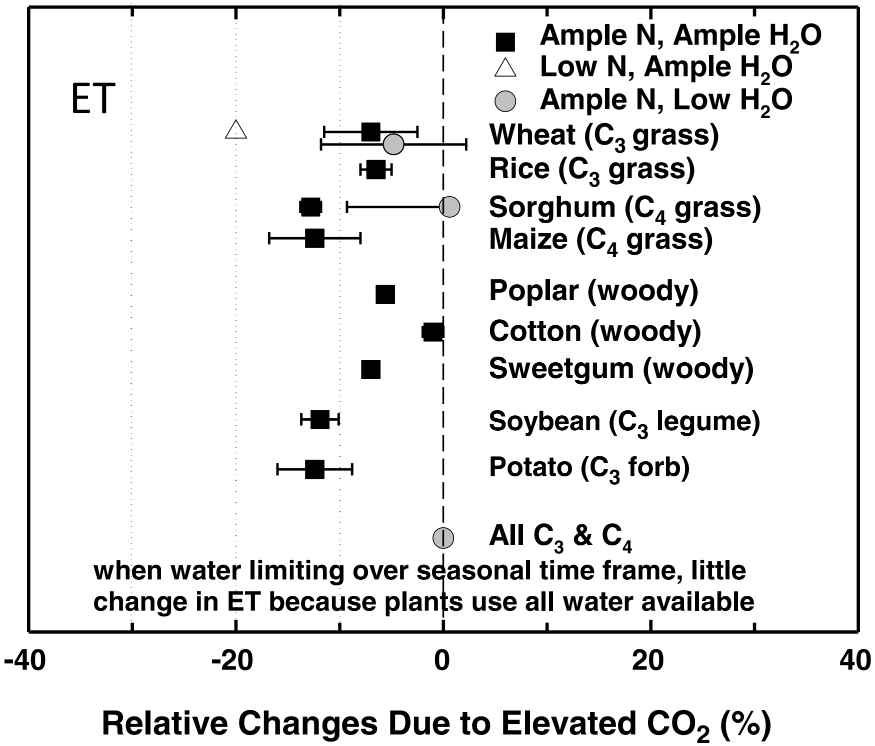
C_4 crops by ~10% (due to water stress reduction)

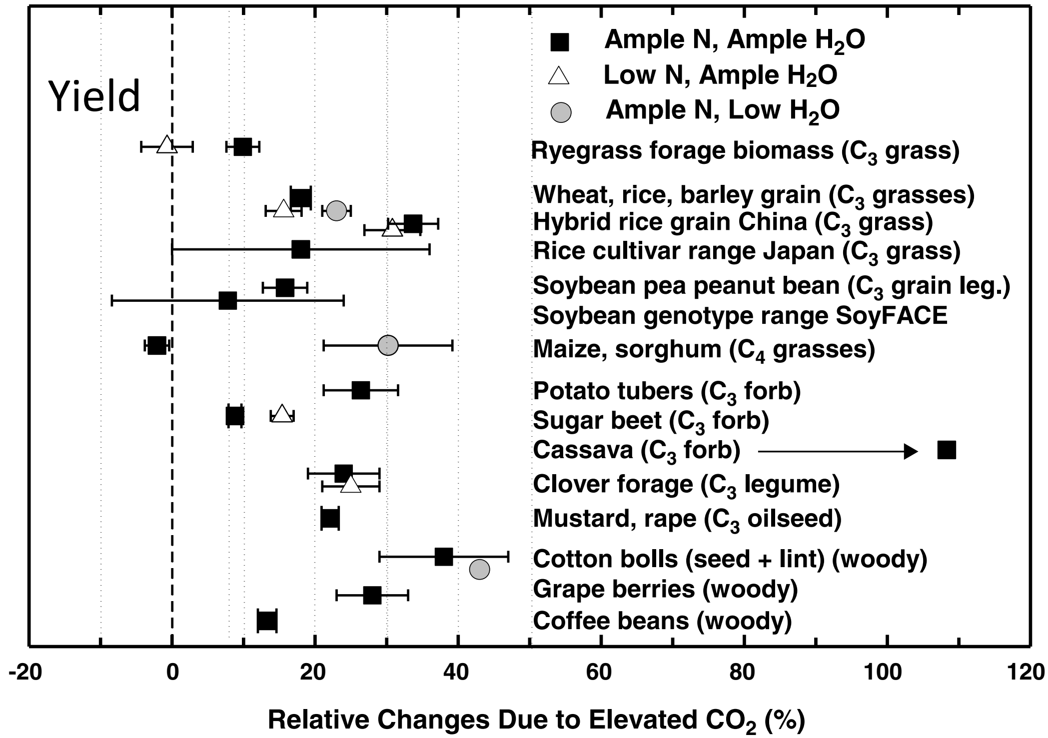


- Reduces crop water use (transpiration) by ~ 10%
- Reduces crop quality (lower nutrients content (zinc, aluminium); unbalance C-N ratio leads to lower protein content

Crop Responses to elevated [CO_2]

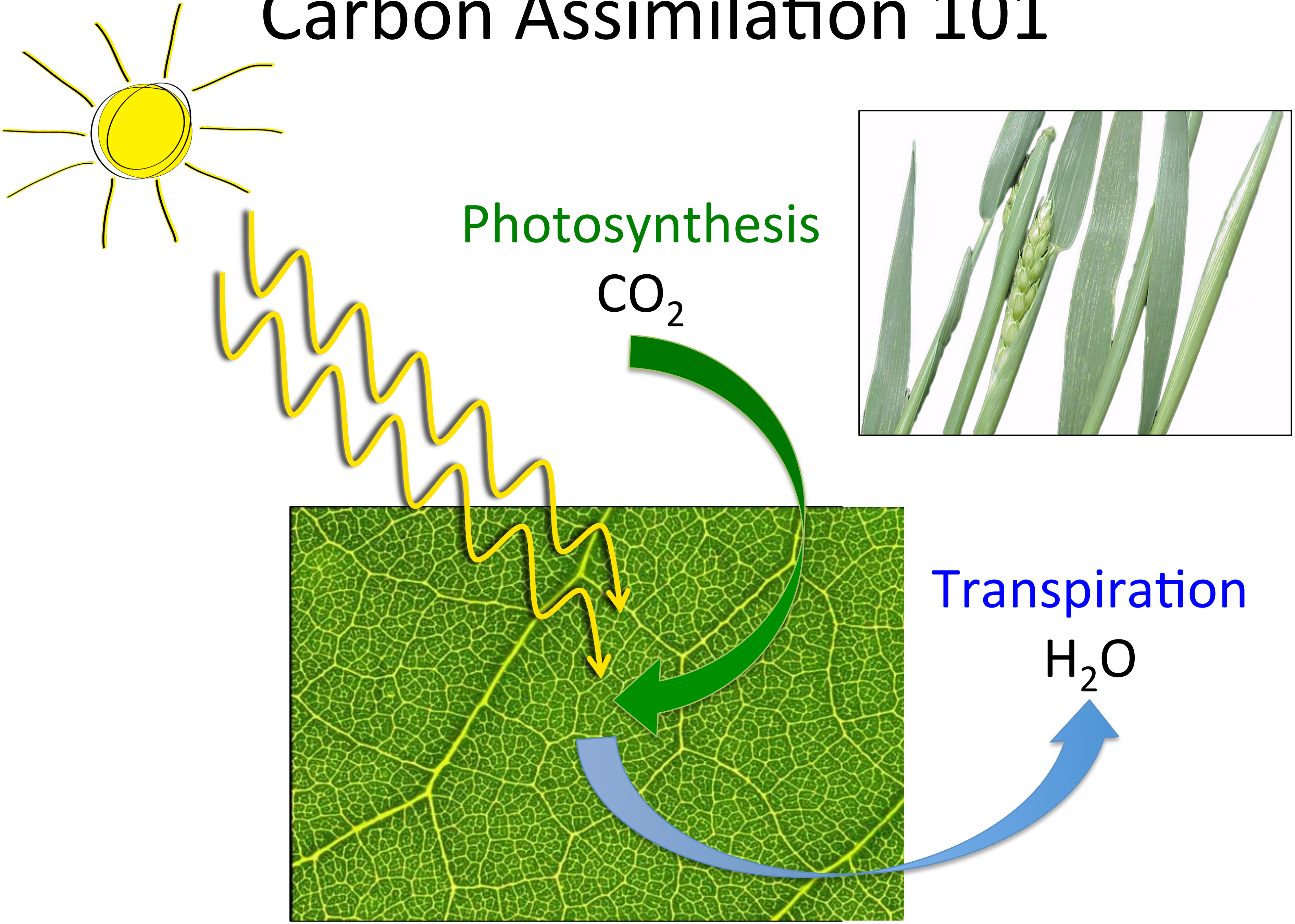
- Evapotranspiration of both C_3 and C_4 plants decrease by about 10% on average
- Corresponding yields of most C_3 grain crops increase on average by about 19%
- Yields of C_4 crops increase only when water is limiting, as in this case [CO_2] stimulate crop growth via improved water conservation



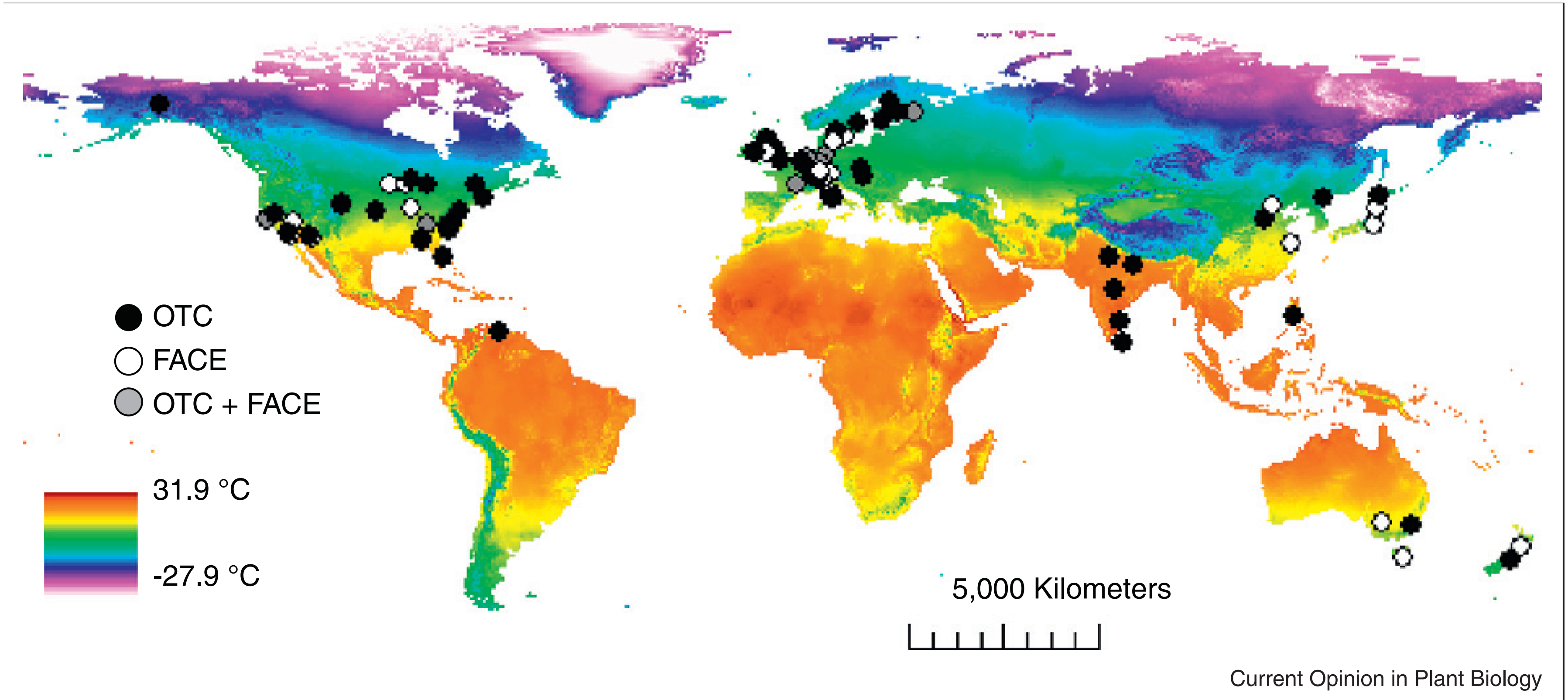


Synthesis open-top chamber (OTC) and free air CO_2 enrichment (FACE) experiments Kimball, 2016

Carbon Assimilation 101



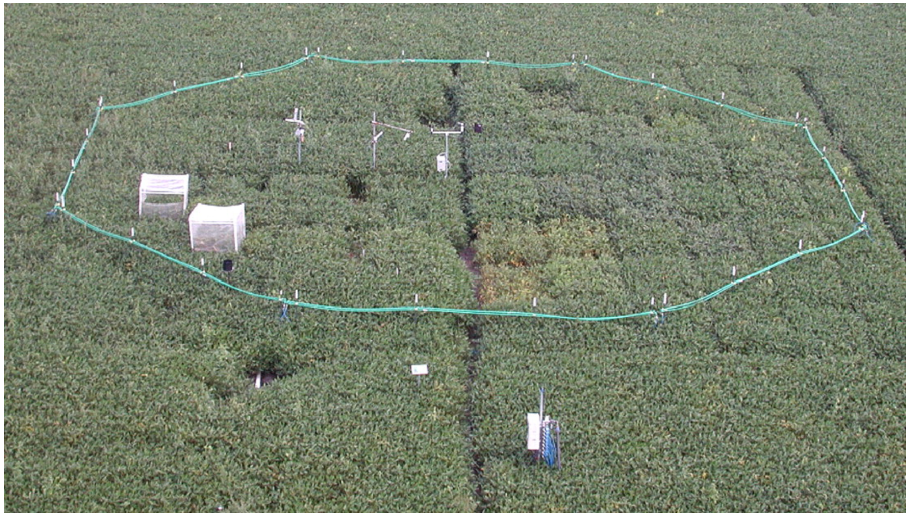
Location of Experimental Sites



→ Mostly located in the northern hemisphere (USA, Japan, Germany)
→ Little knowledge of spatial variations in the global impacts
→ Focus on important crops (wheat, rice, soybean…) rather than less common ones (eg millet, cassava, coffee)

Free-Air CO_2 enrichment (FACE)

Rice-FACE, Japan



Soy-FACE, Illinois

AgFACE, Australia

New study …

nature climate change

LETTERS

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Regional disparities in the beneficial effects of rising CO_2 concentrations on crop water productivity

Delphine Deryng[1,2,3]*, Joshua Elliott[1,2], Christian Folberth[4,5], Christoph Müller[6], Thomas A. M. Pugh[7,8], Kenneth J. Boote[9], Declan Conway[10], Alex C. Ruane[11,2], Dieter Gerten[6,12], James W. Jones[9], Nikolay Khabarov[5], Stefan Olin[13], Sibyll Schaphoff[6], Erwin Schmid[14], Hong Yang[4] and Cynthia Rosenzweig[11,2]

1. Multi-model assessment of the impacts of climate change on crop yield and ET
2. Comprehensive model/observation comparison in respects to CO_2 effects
3. Global analysis of the spatial variations in the CO_2 effects on crops
4. Attribution of model uncertainties

Multi-model Assessment

- 6 Global Gridded Crop Models (GGCMs):

EPIC	pDSSAT	LPJmL
GEPIC	PEGASUS	LPJ-GUESS

Site-based

Ecosystem

- Driven by 5 Global Climate Models (GCMs)

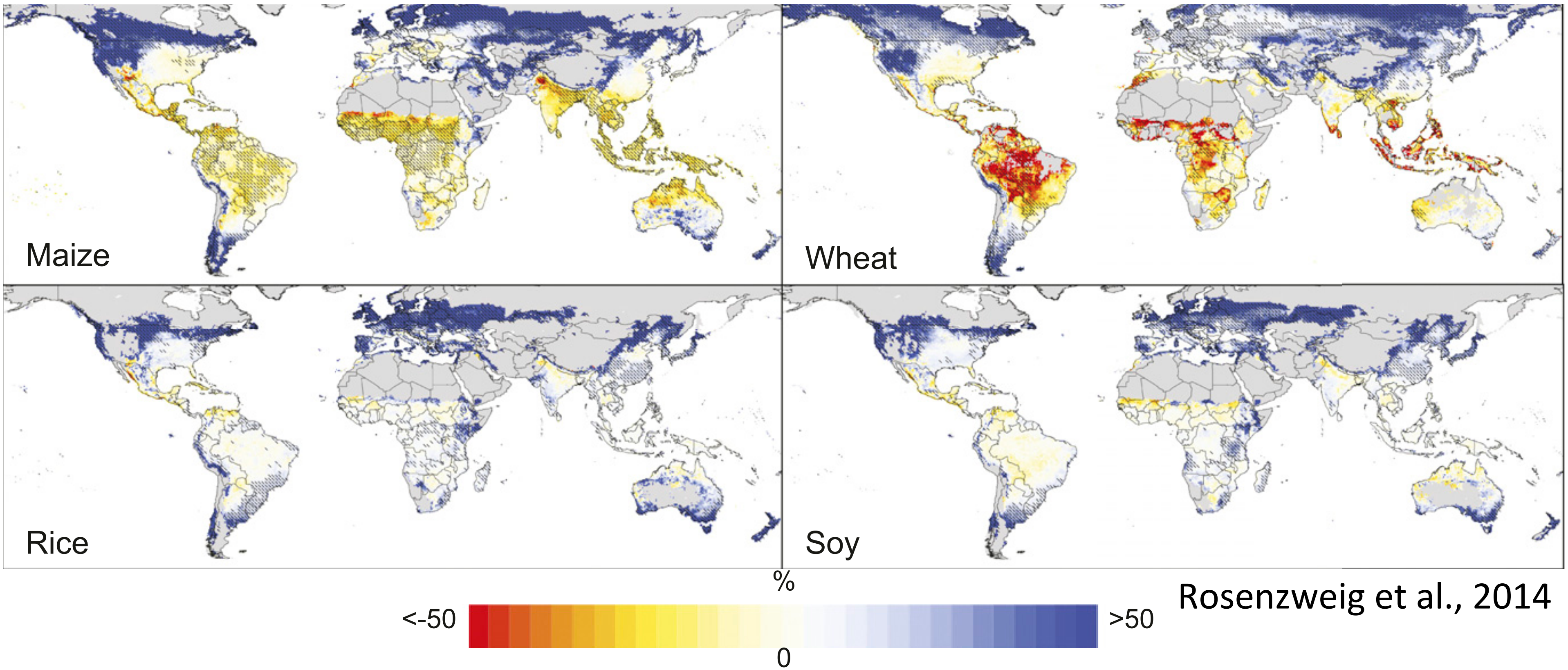
HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2-M, NorESM1-M

- under RCP 8.5 (Climate+CO_2 effects)
- Simulated crop yield, evapotranspiration, and more…

Maize	C_4 photosynthesis
Wheat	C_3 photosynthesis
Rice	C_3 photosynthesis
Soybean	C_3 photosynthesis, N-fixing legume

Projected Impacts on Crop Yields

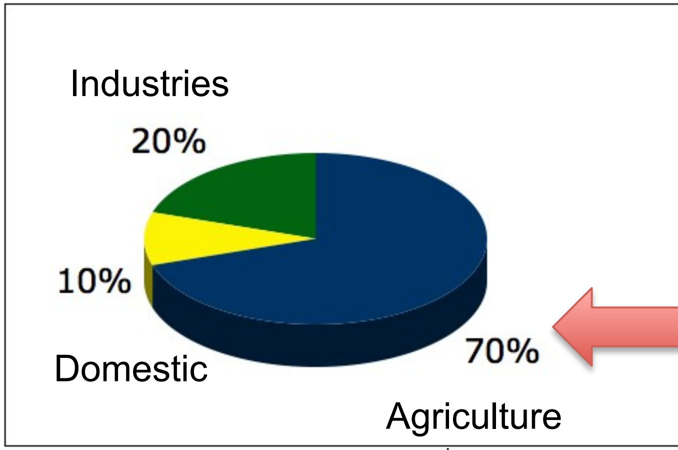
Simulated change in crop yields in 2080 relative to 2000 under RCP 8.5
CO_2 concentrations double relative to present-day



Rosenzweig et al., 2014

Median across 30 combinations of 6 global crop models and 5 global climate models

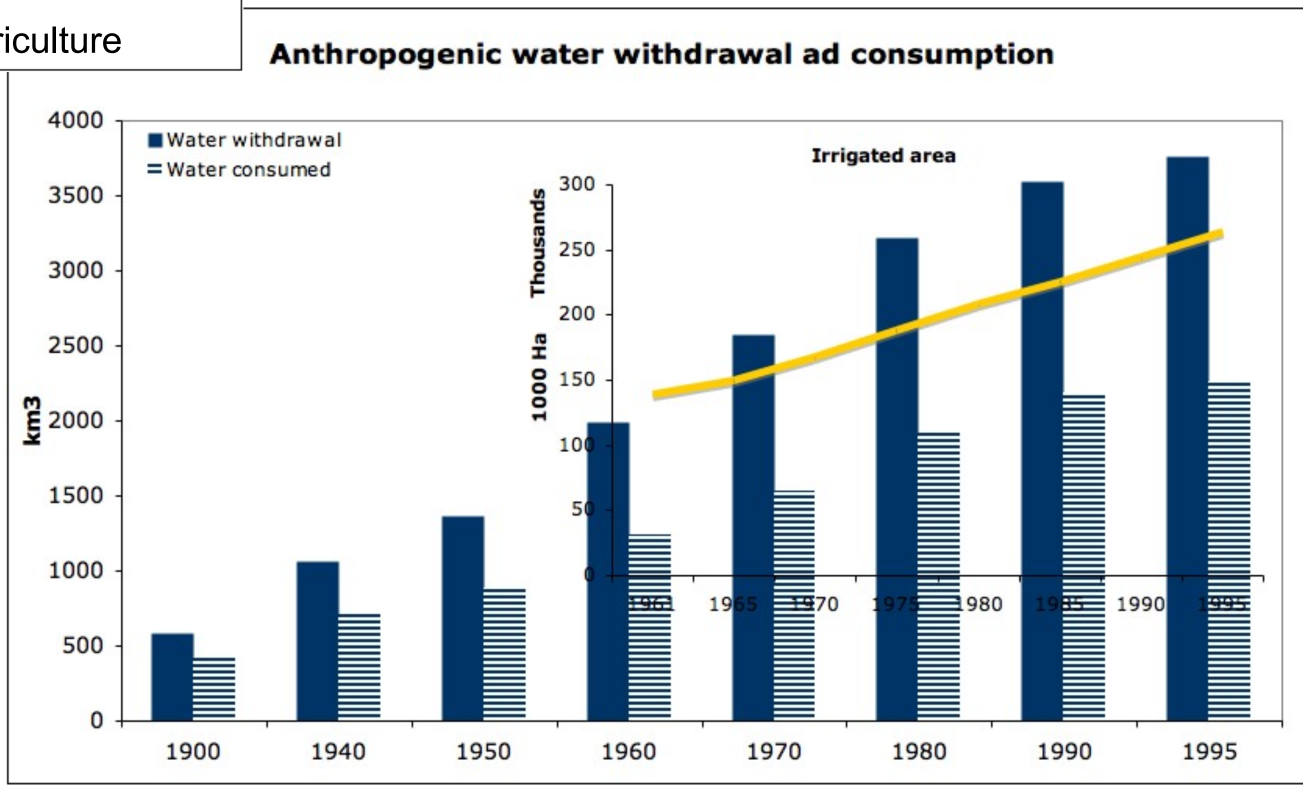
Global water use



Total water withdrawal: 3700 km^3/yr

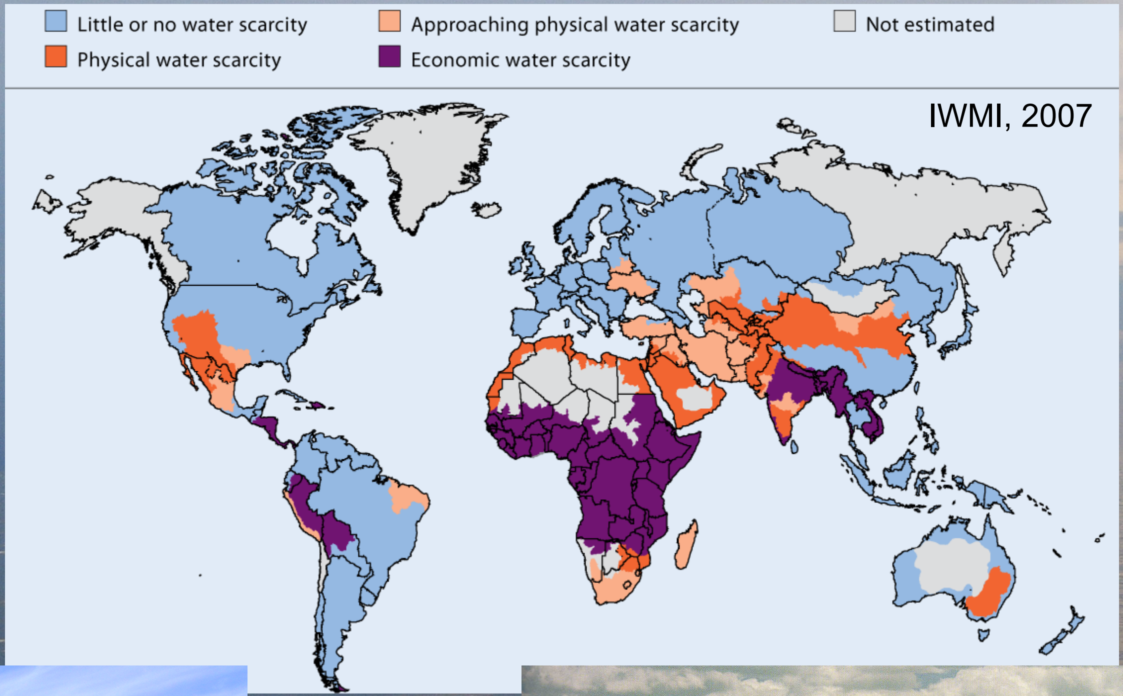
Agriculture water withdrawal: 2590 km^3/yr

Agriculture sector uses 70% of global freshwater use!



Pacific Institute, 2007
FAO, 2008

Water availability and scarcity

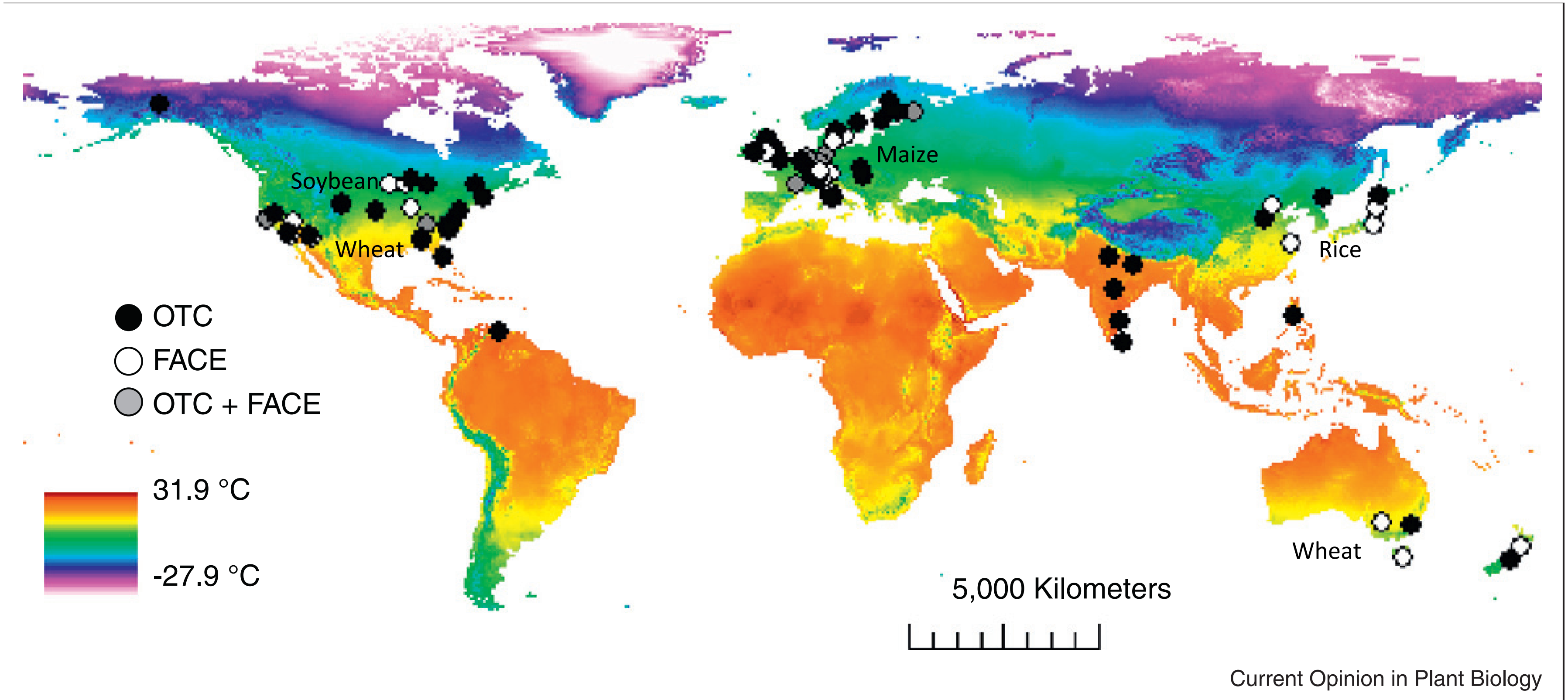


Can elevated atmospheric [CO_2] contribute to produce more food with less water?

- Crop Water Productivity
- CWP is the ratio of crop yield to total water use throughout the crop development period (AET)
- CWP = Yield/AET

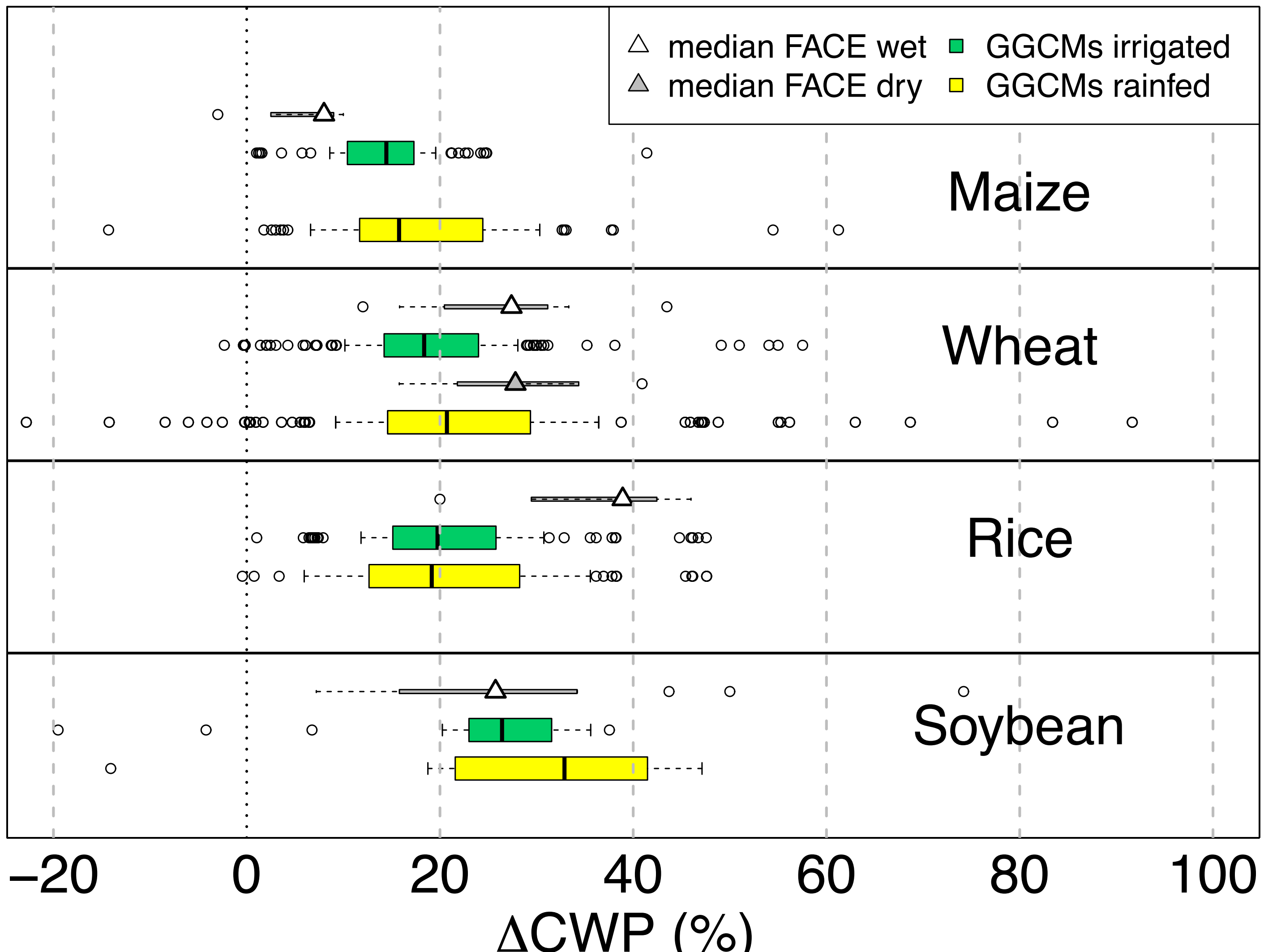
AET=actual evapotranspiration

Location of FACE where data on both yield and AET are available



→ Wheat in two sites (Arizona, USA & SE Australia)
→ Maize in Germany
→ Rice in two sites (Japan & China)
→ Soybean in Illinois, USA

Model/Observation Comparison



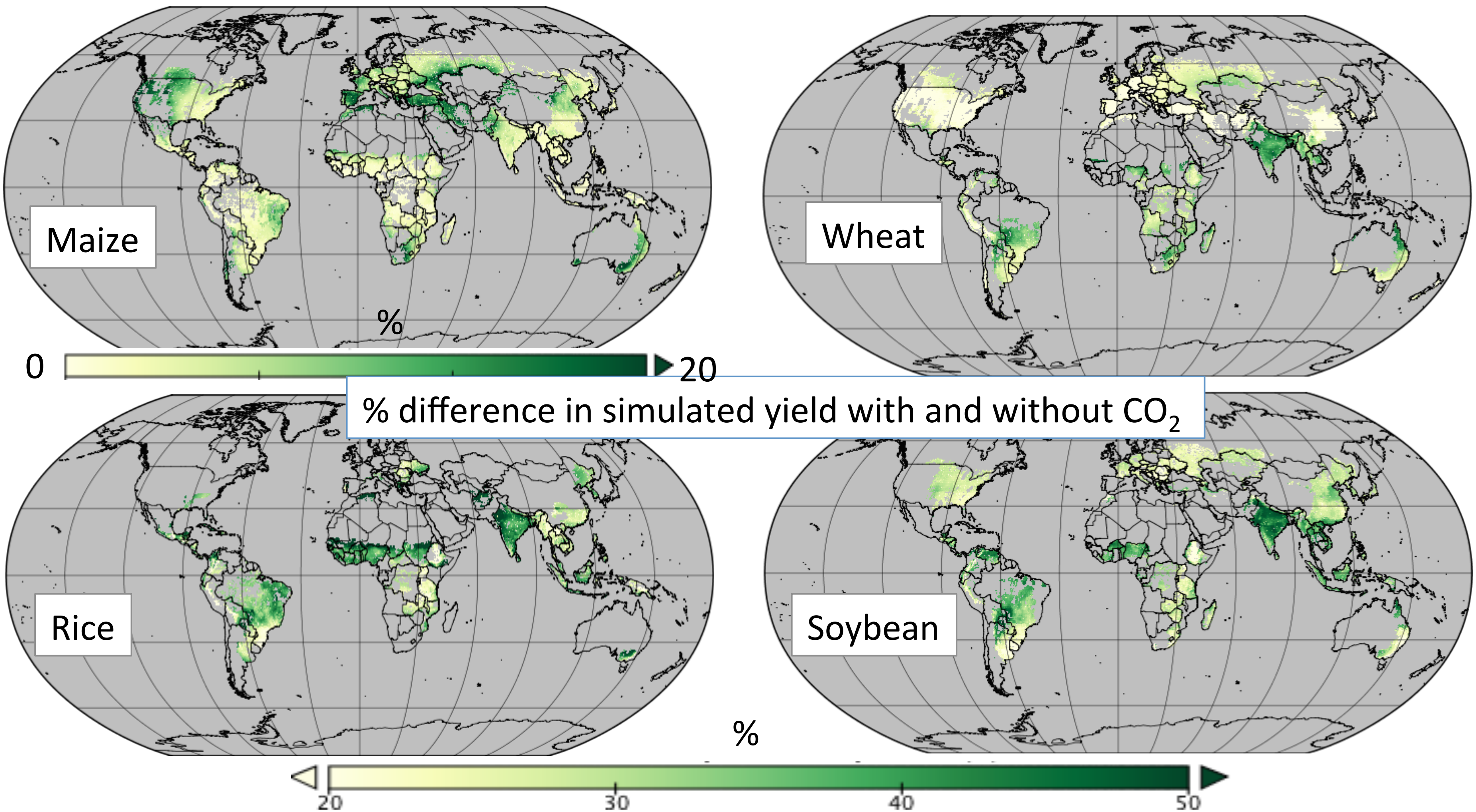
Global Impacts

Wheat (C_3 crop)	Climate change with CO_2 effects	Climate change without CO_2 effects
Yield	+3 [-1;+14] %	-23 [-28;-15] %
Evapotranspiration	-11 [-21;-6] %	-7 [-12;-5] %
Crop water productivity	+27 [7;37] %	-17 [-24;-1] %

Maize (C_4 crop)	Climate change with CO_2 effects	Climate change without CO_2 effects
Yield	-9 [-16;+1] %	-21 [-28;-13] %
Evapotranspiration	-17 [-24;-5] %	-8 [-13;-2] %
Crop water productivity	+13 [3;22] %	-13 [-22;-2] %

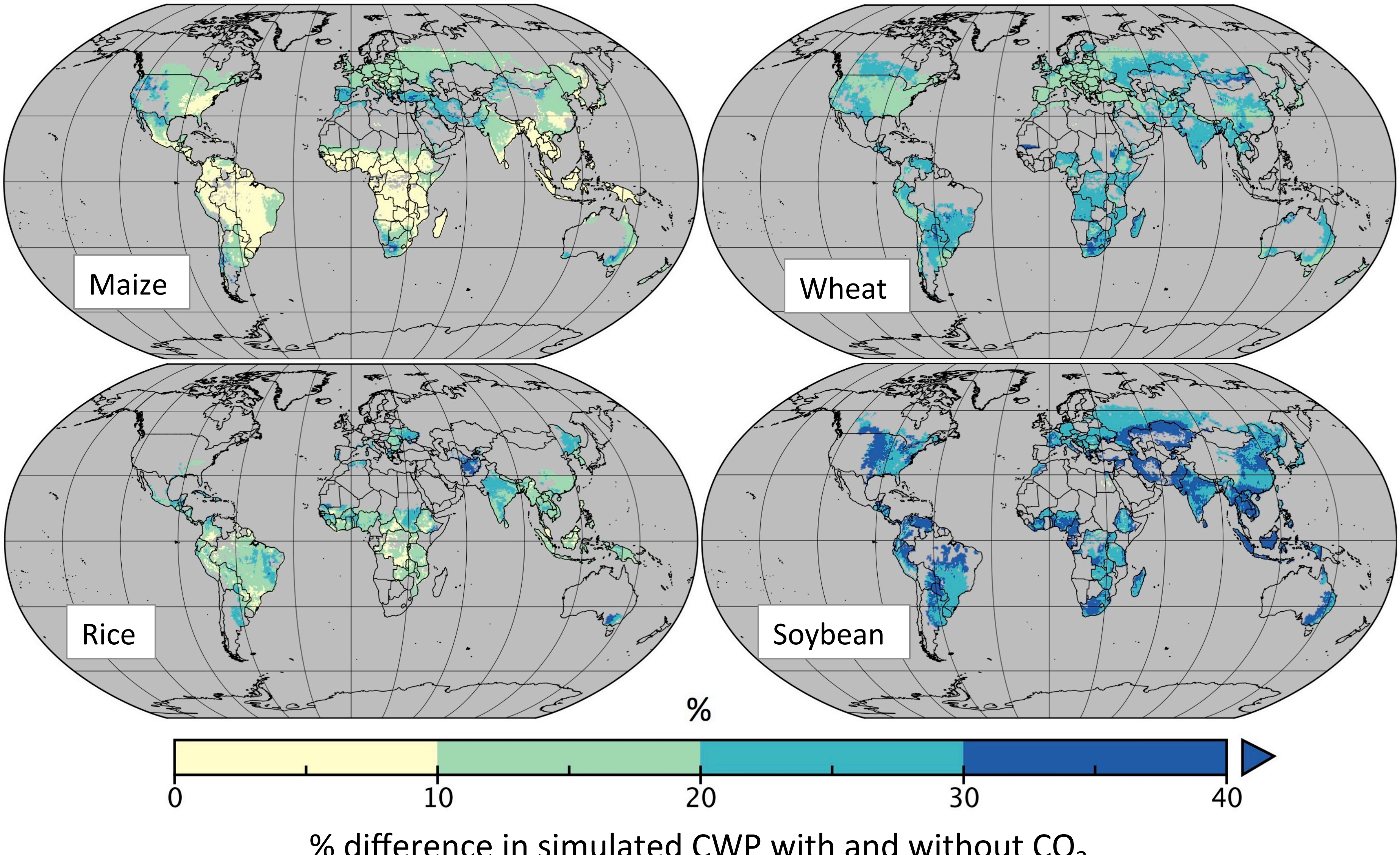
Spatial variations: CO_2 effects on yield (rainfed)

$[CO_2]$ levels correspond to year 2050
under a business as usual greenhouse gases emission scenario



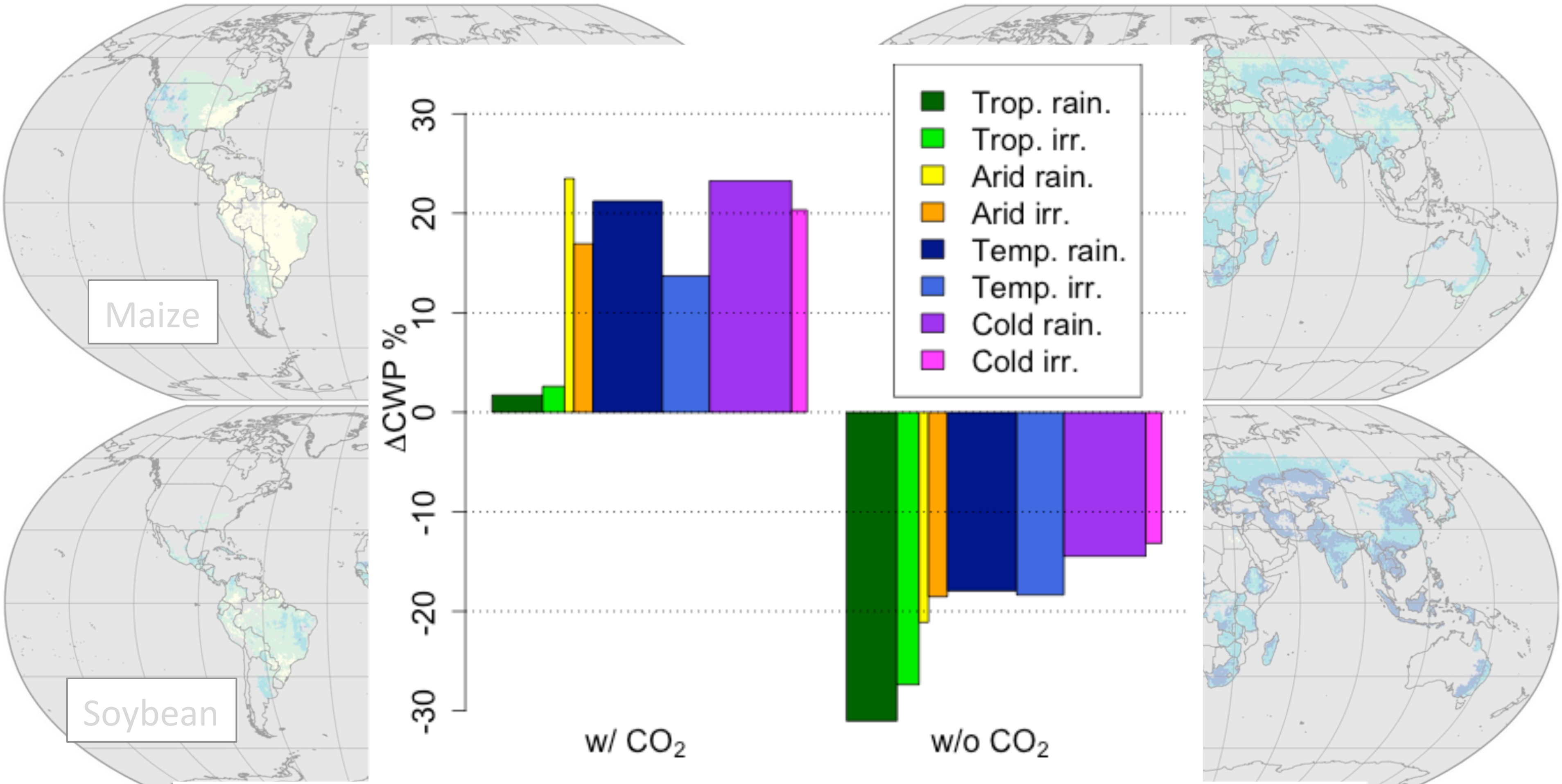
Median across 30 combinations of 6 global crop models and 5 global climate models

Spatial variations: CO_2 effects on CWP (rainfed)

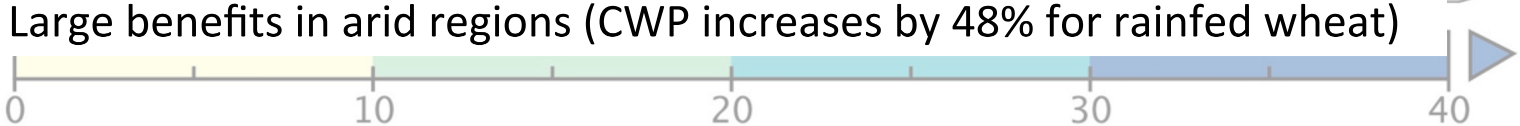


[CO_2] levels correspond to year 2050 under RCP 8.5 - median across the GGCM-GCM ensemble

Summary across climatic regions



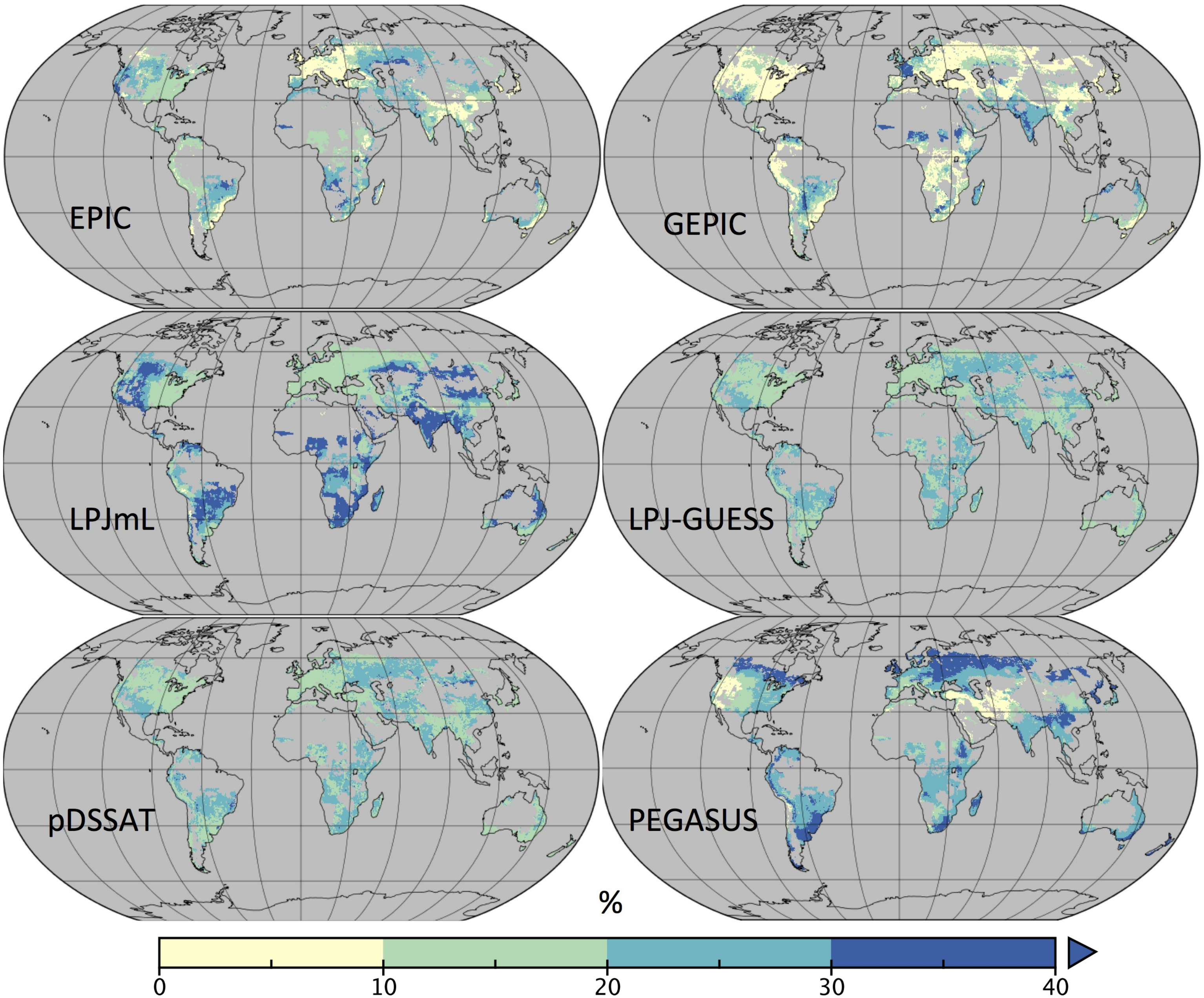
Large benefits in arid regions (CWP increases by 48% for rainfed wheat)



% difference in simulated CWP with and without CO_2

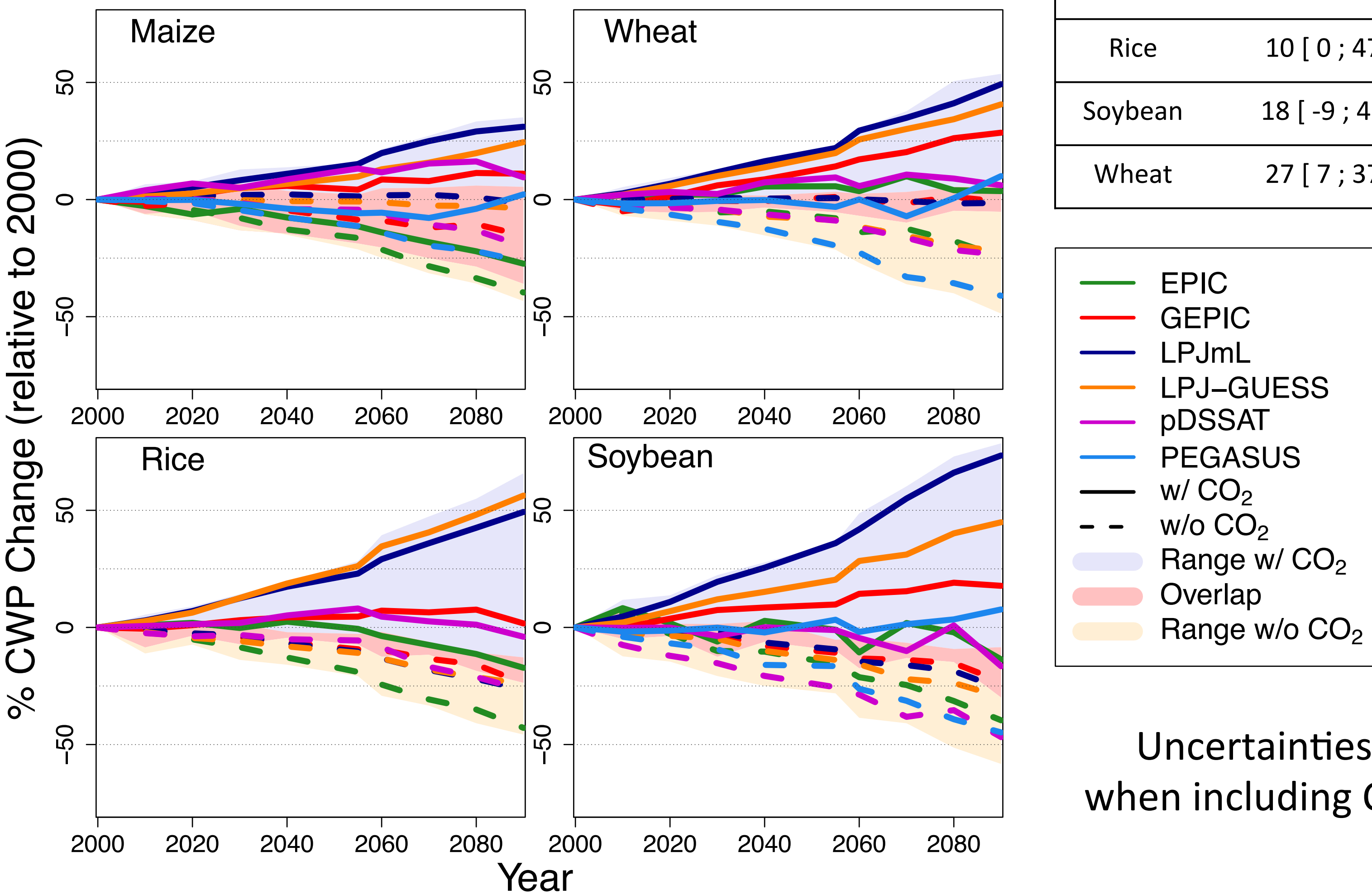
[CO_2] levels correspond to year 2050 under RCP 8.5 - median across the GGCM-GCM ensemble

Wheat CO_2 effects on CWP
[CO_2] levels correspond to year 2050 under RCP 8.5 - median across 5 GCMs



Large uncertainties in impact model projections

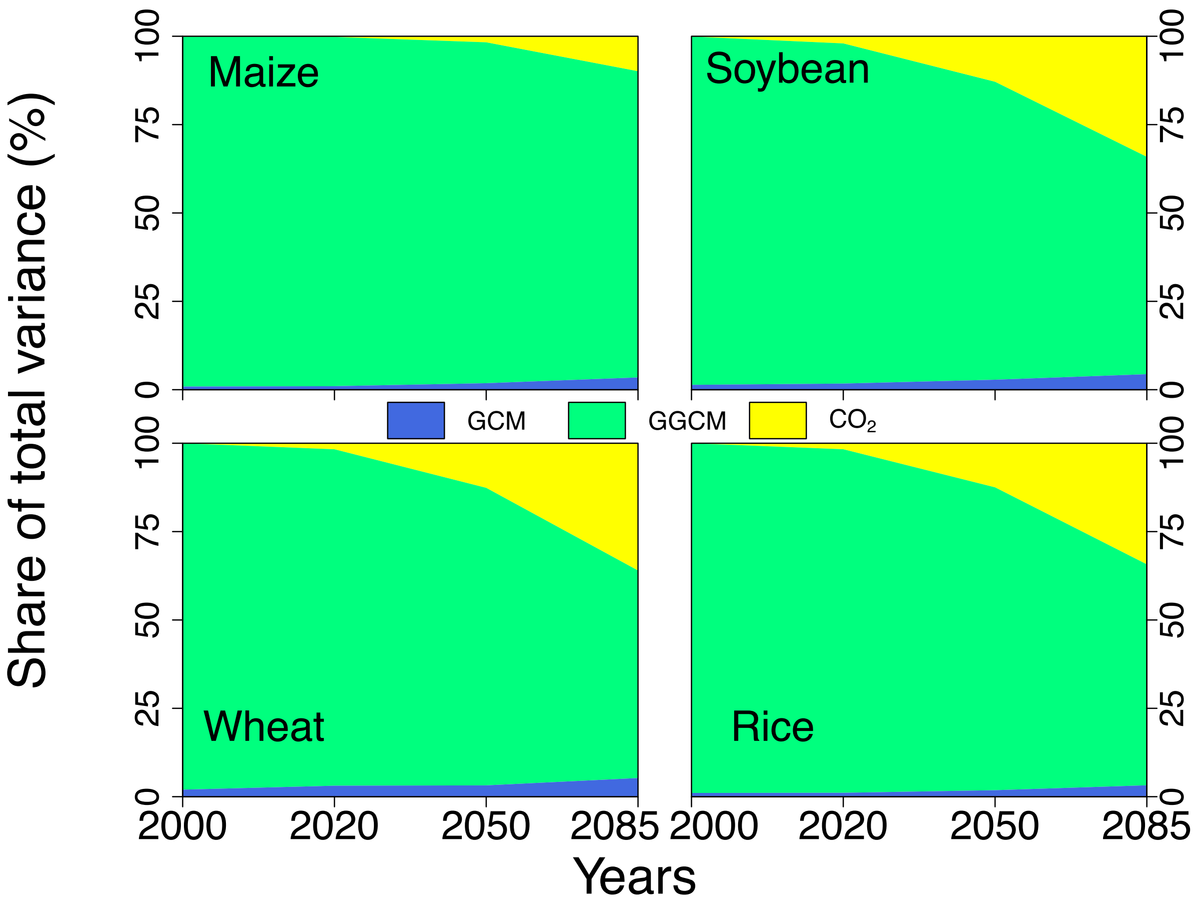
6 different crop models driven by climate data from 5 different climate models:



	Climate change with CO_2	Climate change without CO_2
Maize	13 [3 ; 22] %	-13 [-22 ; -2] %
Rice	10 [0 ; 47] %	-23 [-27 ; -17] %
Soybean	18 [-9 ; 42] %	-26 [-40 ; -19] %
Wheat	27 [7 ; 37] %	-17 [-24 ; -1] %

Uncertainties double when including CO_2 effects

Source of Uncertainties in Impacts Projections



- Climate signal (climate change projections from GCMs)
- Crop simulation methodology (parameterization, ET equation, nitrogen stress, extreme heat sensitivity, phenology & planting date decision/cultivar choice…)
- CO_2 sensitivity methodology (Radiation Use Efficiency vs Photosynthesis-Respiration)

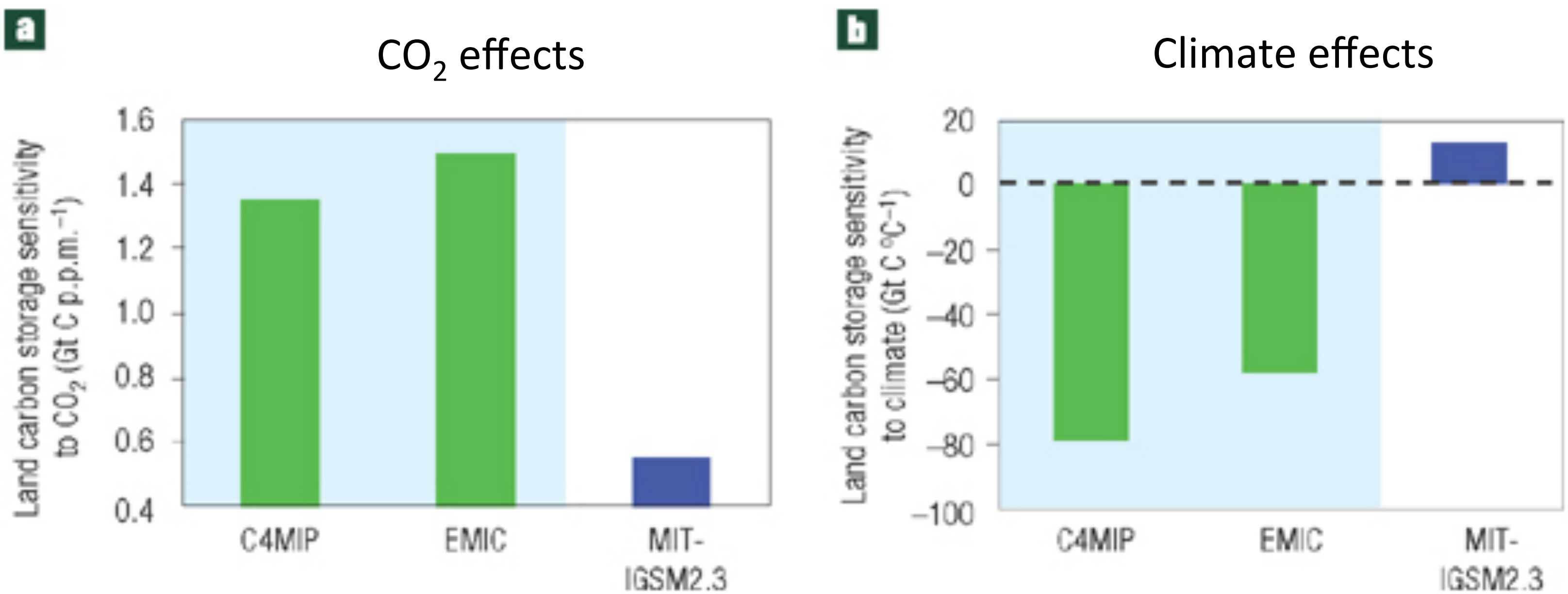
Climate Adaptation Strategies

- Increase fertilizer application – CO_2 effects are stronger for well-fertilizer crops
- Elevated CO_2 could reduce irrigation demand (in some cases)
- Elevated CO_2 could help rainfed crops to cop with water stress

→ Choice of crop type (switch to a less water demanding crop)

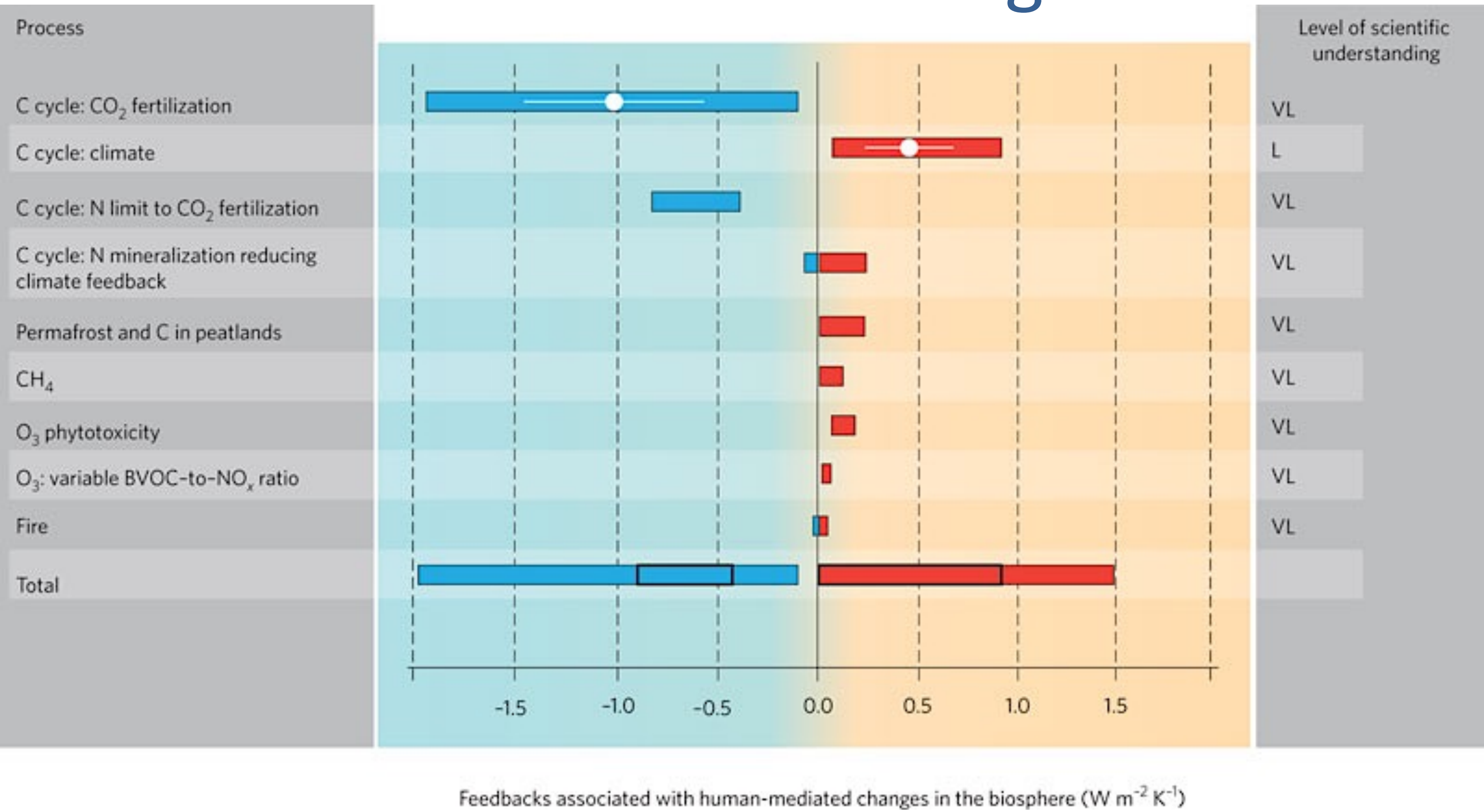
- Crop genetics (develop cultivars adapted to high CO_2 levels

Role of CO_2 in GCMs & EMIC Carbon Cycle–Climate Feedbacks



Increases in CO_2 and temperature have opposite effects on the carbon sink: increases in atmospheric carbon dioxide stimulate photosynthetic uptake of CO_2 in a "CO_2 fertilization" effect that dampens anthropogenic-induced increases in atmospheric CO_2, and increases terrestrial carbon storage by 1.35 Gt-C/ppm increase in atmospheric CO_2 (Bonan, 2008)

Feedback processes contributing to radiative forcings



Total positive radiative forcings resulting from feedbacks between the terrestrial biosphere and the atmosphere are estimated to reach up to 0.9 or 1.5 W m−2 K−1 towards the end of the twenty-first century, depending on the extent to which interactions with the nitrogen cycle stimulate or limit carbon sequestration. This substantially reduces and potentially even eliminates the cooling effect owing to carbon dioxide fertilization of the terrestrial biota. (Arneth et al., 2010)

Next steps

- Expand FACE experience and develop collaboration between agronomists and crop modelers

AgMIP The Agricultural Model Intercomparison and Improvement Project

- CTWN modeling sensitivity (Global Gridded Crop Modeling Initiative phase 2)

- Communication, science/policy interaction

→ understand challenges for adaptation by practitioners, farmers…etc.

e.g. Adaptation Futures conference in Rotterdam, May 10-13

ADAPTATION FUTURES 2016 practices and solutions

Thank you!

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Ref. Deryng et al., (2016) doi:10.1038/nclimate2995

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